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Short Communication

Evaluating Soil Temperature in Predicting Phenology in Wheat (*Triticum* sp.) Crop

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In view of increasing evidence of global climate change and widespread local weather aberrations, role of temperature mediating the crop phenology is getting a renewed interest. An improvement in thermal time concept could be necessary, in order to predict the growth and behaviour of the crop under the change in climatic condition. Temperature is the prime factor in driving growth and development in wheat (Jamieson *et al.*, 1995; McMaster and Wilhelm, 1998) and the growth modelling is fundamentally based on the thermal concept. Thermal time is generally expressed as growing degree days (GDD), and usually calculated from linearly accumulating the air temperature above a crop-specific base temperature. It has been proposed long ago that during early growth stages, soil temperature could be better in thermal time accumulation like GDD (Duncan *et al.*, 1973; Swan *et al.*, 1987), although no such attempts to establish the postulation have been reported. It has been reported that wheat shoot apex directly perceives temperature and we assume a constant relationship between air and shoot-apex temperature (McMaster and Wilhelm, 1998), and thus, once the shoot apex is elevated over soil surface, air temperature may predict in a better way than soil temperature. Air temperature remaining the same, soil temperature is modified by management practices like tillage, irrigation, residue management, mulching etc., and literature is replete with reports of crop growth and development as mediated by changes in soil thermal regime (e.g. Stone *et al.*, 1999; Ramakrishna *et al.*, 2006; Chakraborty *et al.*, 2008; Zhang *et al.*, 2011). It may appear that prediction of various phonological stages may be improved by using soil temperature in computing the GDDs. Keeping this in background, a study was conducted to evaluate the improvement of predictability of wheat phenology, if any, based on soil temperature under various agronomic management practices.

Data on major phonological stages in wheat like crown root initiation, tillering (when 50% of main stems bear tillers), late jointing or booting, flowering, dough and maturity were collected from published literatures pertaining to four wheat growing areas across north-west Delhi. Daily maximum and minimum air- and soil-temperature at 5 cm depth were also recorded for the specific site-year. The accumulated thermal air- and soil-time (in GDD) from sowing to different growth stages was calculated as growing degree-days with a base temperature of 5^0C (Table 1). These data was applied to predict the occurrence of specific growth stages in wheat (as above). Data recorded from a field experiment conducted during 2005-06 with 4 cultivars of wheat (HD 2936, HDR 77, HI 8498 and PBW 343) under 9 different dates of sowing (at 15 days interval starting from 7th October 2005 to 7th February 2006) at IARI farm was used as the validation dataset. Three statistics were used to estimate

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Table 1. Statistics comparing use of air temperature (T_{air}) or soil temperature (T_{soil}) to calculate growing degree days between selected wheat growth stages for the validation dataset

Developmental interval*	Days taken (average)	r^2		RMSE		SRES		SARES	
		T_{air}	T_{soil}	T_{air}	T_{soil}	T_{air}	T_{soil}	T_{air}	T_{soil}
S-CRI	20	0.79	0.84	5.2	4.9	17	12	53	50
S-T	45	0.66	0.69	8.3	7.0	-22	-15	46	51
S-B	70	0.12	0.10	21.0	19.6	64	79	196	227
S-F	90	0.27	0.19	10.5	17.8	-17	-28	145	178
S-D	115	0.5	0.47	8.8	10.5	30	-25	110	142
S-H	140	0.57	0.50	7.6	11.9	26	-13	120	137

RMSE: Root Mean Square Error ; SRES: Sum of residuals; SARES: Sum of absolute residuals; * Growth stages: S, sowing; CRI, crown root initiation; T, tillering; B, booting or late jointing; F, flowering; D, dough; and H, harvesting

predictability of wheat phenolgy using air- and soil- temperature: (1) paired t-test (whether difference in prediction existed between using soil- and air-temperatures); (2) simple linear regressions (to determine the r^2); and (3) three validation indices - root mean square error (RMSE), sum of the residuals (SRES) and sum of the absolute residuals (SARES).

When considering all three statistics (paired t-test, r^2 and RMSE), there were no instance when using soil temperature significantly improved the predictive accuracy compared with air-temperature (Table 1). The greatest improvement from using soil temperature came in predicting crown root initiation. For prediction between sowing and CRI stage, r^2 increased along with lowering of RMSE, SRES and SARES values. In case of sowing to tillering period, there is an improvement in r^2 with reduction in RMSE and SRES, although SARES showed no improvement. For both the stages, RMSE is small, indicating good agreement between observed and predicted dates. SRES and SARES are small for these two growth stages, suggesting none or negligible bias towards over- or under-predicting the growth stages. However for predicting of growth stages after tillering (booting, flowering, dough and harvesting), most evaluation statistics indicated that soil temperature does not offer an advantage, and in many cases, air temperature shows better prediction that than by using soil temperature to calculate the GDD.

Predicted date of occurrence of a specific growth stage using air- or soil-temperature compared with the observed date confirms the validation results presented in Table 1. Pairs of dates predicted from air- and soil-temperature were plotted against same observed date in Fig. 1. It is apparent that using air-temperature provides mostly the better or similar prediction. For example, from sowing to CRI, there are three cases where air- is better than the soil-temperature (circles closer to the 1:1 line than stars), two cases with no difference in predictability using air- or soil-temperature (circles and stars are at same distance from 1:1 line) and one instance where soil-temperature provides the best predictability (stars closer to 1:1 line than circles). Paired t-test results confirm this as there was no significant difference in predicting a growth stage, other than CRI and tillering, by using soil- or air-temperature.

The SRES and SARES values indicate similar predictability for air- and soil-temperature. Both the predictions were early for sowing to booting, but for other stages, early and late predictions were similar among the site-years.

A close similarity of accumulated GDD from air- and soil-temperature was observed. Whenever, T_{mean} is less than the base temperature, no GDD was accumulated, regardless of the observed air- or soil-temperature. When calculating mean GDD from sowing to maturity

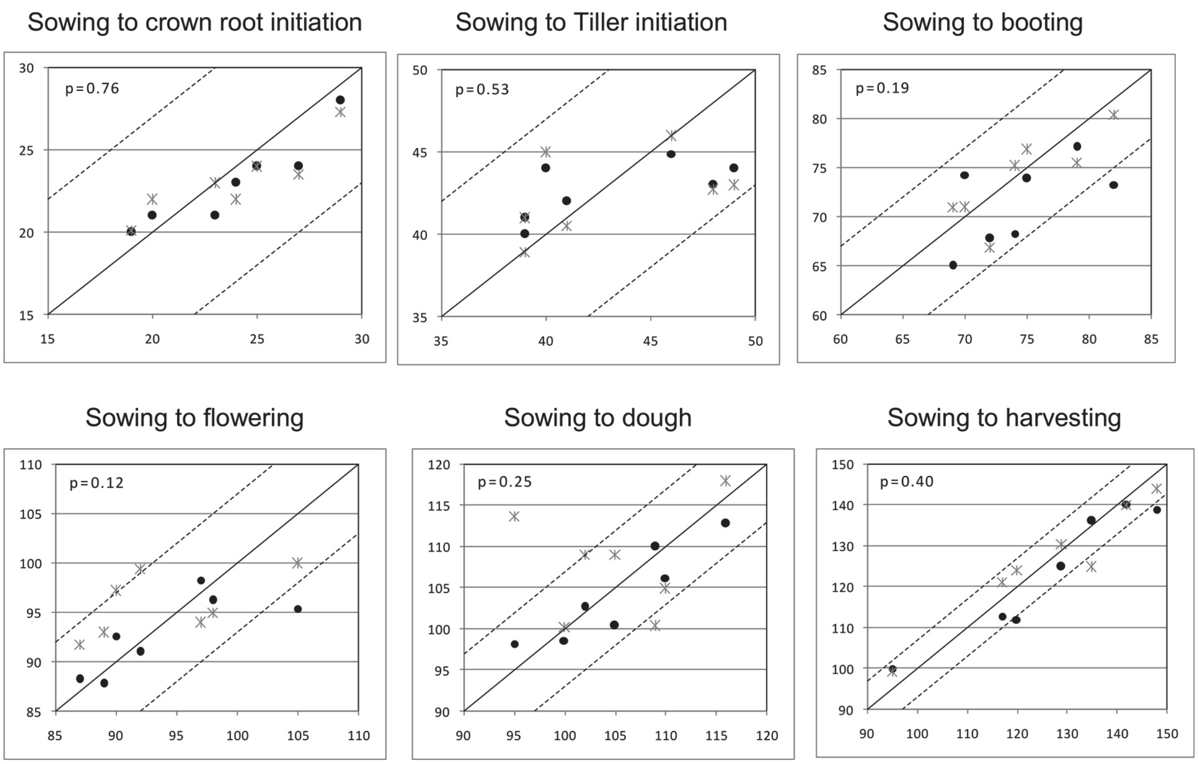

Fig. 1. Validation results for predicting major growth stages using air temperature (circles) and soil temperature (stars). The solid line is the 1:1 line, with dashed lines representing ±7 d from 1:1 line. Paired t-test results for using soil- and air-temperatures to predict specific growth stage are presented in the upper left corner of each graph

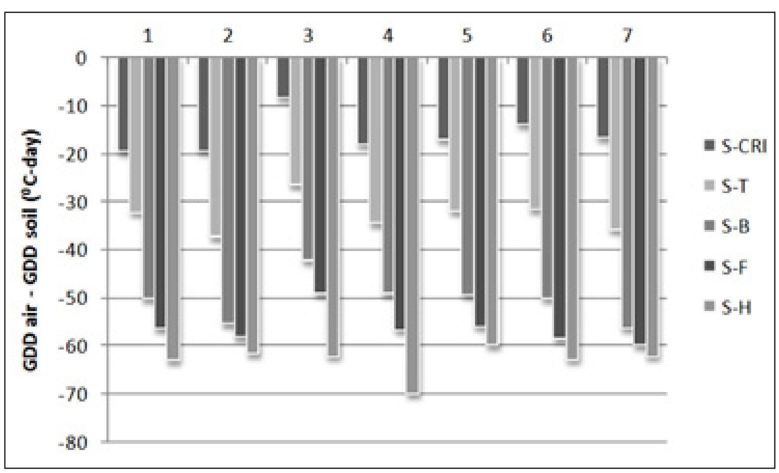

Fig. 2. Comparison of air and soil- growing degree days (GDD) over the validation data sets (Delhi region) (1=7th Oct, 2=21st Oct, 3=7th Nov, 4=21st Nov, 5=7th Dec, 6=21st Dec, 7=7th Jan as dates of sowing of wheat crop)

for all dates of sowing, soil accumulated 63 GDD more than air, which is about 15% of the total. If intervals are taken, soil accumulated 16, 33, 50, 56 and 63 GDD higher than the air, for sowing to CRI, tillering, booting, flowering and harvest, respectively (Fig. 2). Differences for calculating thermal time were always a small proportion for either a specific interval or the total GDD accumulated to that event (<10% from all stages up to dough and 15% for maturity).

The reason for greater soil GDD accumulation from sowing to tillering (52%) and booting (79%) may be explained by canopy development of wheat crop. Canopy alters the near-surface soil temperature through modifying the quantity of intercepted radiation and wind speed. Initially, until CRI stage, the leaf area index is small. LAI rapidly increases along with increase in plant height up to tillering and booting. After that, the LAI decreases due to drying and senescence of leaves and the plant almost reached to its optimum height. Reduced LAI allows more radiation to reach to soil surface, but wind speed over the soil surface is reduced under full canopy, the combined effect explains the observed difference in GDD accumulation.

Results of the present study implies that use of soil as the basis for GDD calculation does not improve the ability to predict wheat phenology from accumulated thermal time (GDD) estimates. Possible explanations could be:

1. Pooling the data across cultivars, climate, soils and management practices might have masked the effect of using soil temperature.
2. Predictions using air temperature were more close to the actual observations (Fig. 1) and in most of the phonological stages (except CRI and tillering), predictions using air and soil temperature was almost similar (explained by the t-test, Fig. 1).
3. In models, it is assumed that a consistent relationship exists between shoot apex temperature and the air temperature. In our results, although soil-accumulated GDD is marginally higher than the air-, the basic relationship seems true. The differnece between air- and soil-acuumulated GDD was also similar among the sowing dates.

Thus, it can be concluded that using soil temperature does not improve the overall predictive accuracy for wheat phenology. Our study is based on several broad phenological stages and prediction may improve when precisely defined stages are considered. This requires further detailed experimentation and data collection.

References

Chakraborty, D., Nagarajan, S., Aggarwal, P., Gupta, V.K., Tomar, R.K., Garg, R.N., Sahoo, R.N., Sarkar, A., Chopra, U.K., Sundara Sarma, K.S. and Kalra, N. 2008. Effect of mulching on soil and plant water status, and the growth and yield of wheat (*Triticum aestivum* L.) in a semi-arid environment. *Agric. Water Manage.* **95**: 1323-1334.

Duncan, W.G., Davis, D.R. and Chapman, W.H. 1973. Developmental temperatures in corn. *Florida Soil Crop Sci. Soc. Proc.* **32**: 59-62.

Jamiensonm, P.D., Brooking, I.R., Porter, J.R. and Wilson, D.R. 1995. Prediction of wheat appearance in wheat-A question of temperature. *Field Crops Res.* **41**: 35-44.

MacMaster, G. and Wilhelm, W.W. 1995. Is soil temperature better than air temperature for predicting winter wheat phenology? *Agron. J.* **90**: 602-607.

Ramakrishna, A., Tam, H.M. Wani, S.P. and Long, T.D. 2006. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. *Field Crop. Res.* **95**: 115-125.

Stone, P.J., Sorensen, I.B. and Jamieson, P.D. 1999. Effect of soil temperature on phenology, canopy development, biomass and yield of maize in a cool-temperate climate. *Field Crop. Res.* **63**: 169-178.

Swan, J.B., Scnieder E.C., Moncrief, J.F., Paulson, W.H. and Peterson, A.E. 1987. Estimating corn growth, yiled and grain moisture from air growing degree days and residue cover. *Agron. J.* **79**: 53-60.

Zhang, S., Li, P., Yang, X, Wang, Z. and Chen, X. 2011. Effects of tillage and plastic mulch on soil water, growth and yield of spring-sown maize. *Soil Till. Res.* **112**: 92-97.

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